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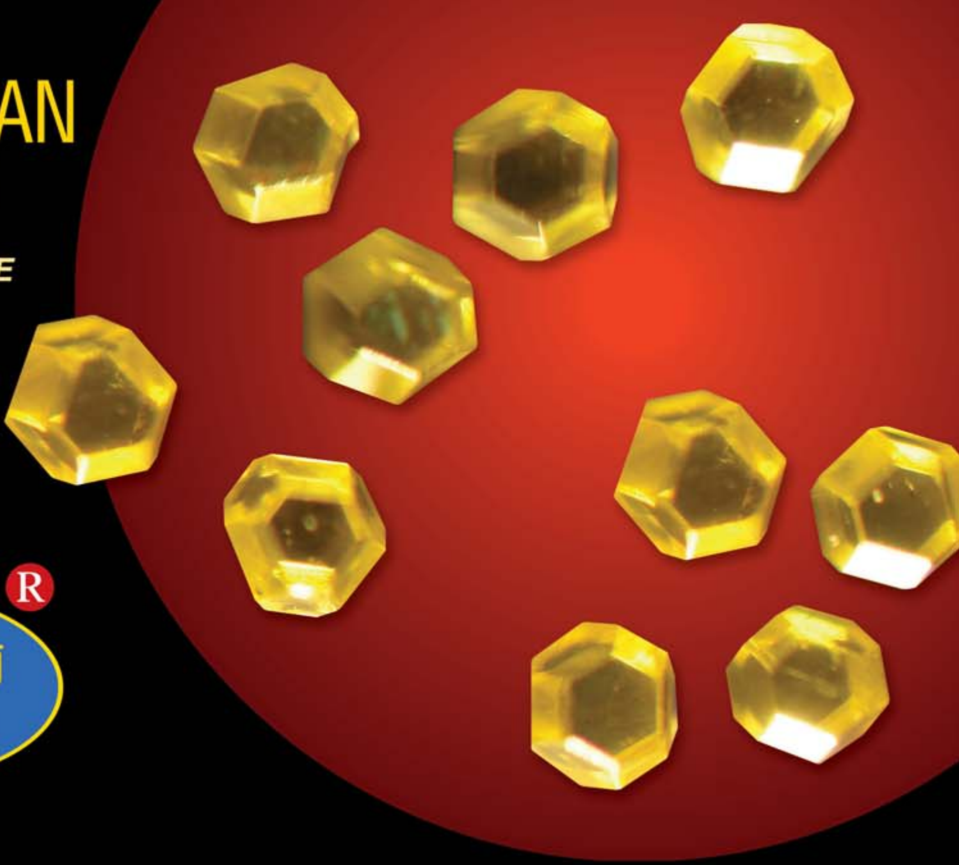

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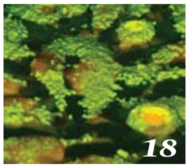
FINER POINTS is the only publication devoted exclusively to the understanding, selection and application of diamond, cubic boron nitride and related materials. It is edited for recipients who are involved in some way with these "superabrasives", either as providers of the materials, producers of products containing the materials or users of these products (e.g., grinding wheels, dressing tools, drill bits, saw blades, sawing wires, cutting tools, polishing compounds, CVD film products, etc.).



COVER PHOTO

A light-conducting silica nanowire wraps a beam of light around a strand of human hair. The nanowires are flexible and can be as slender as 50 nanometers in width, about one-thousandth the width of a hair. Photograph courtesy of Professor Limin Tong and Professor Eric Mazur, Harvard University. In some cases light is propagating along wires just one-third the width of its own wavelength. The wires could aid in the development of optical chips that operate more rapidly and efficiently than today's electronic chips. The tiny structures could also be used to manipulate cells and other microscopic objects. The wires are so fine that they could poke into a cell or a droplet of liquid without disrupting them, yet are extremely sturdy – several times stronger than spider silk, one of the gold standards in the world of materials.

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A Finer Point of View…

A Finer Point of view - Technological Advancements Versus Dangers

I feel very honored to have been elected to my second term as President of the Industrial Diamond Association of America. Many things have changed since my first term in 1996 and most of the things that are most dramatic have been the acceleration of advancements in technology … not just in our industry but also throughout all of science! It is interesting that many times we see these advancements hailed as earth shattering progress and on the other side stand those who protest and herald the doom of mankind brought about by the new technology … Fourteen years ago we saw the first sheep cloned and at that time science considered cloning a vital step in the advancement of medicine because of the possibility of using organs from clones to provide other people those organs they desperately needed to live. On the other side of the argument is the moral issue of humans being created for the sole purpose of using their organs … Of course this is not the only scientific breakthrough that has drawn fire … Every year we are demanding more oil production and people want to limit or restrict exploration … I won't even address what the recent oil leak in the gulf has done to that argument! To counter the increasing demand for oil, science has come up with the battery driven car … Every time we come up with a solution to some environmental problem we end up causing another one. The batteries that run both hybrids and electric cars contain rare elements known as heavy earths and these metals are seriously rare metals and extremely hard to come by. These won't be something you can get at the local Wal-Mart or Home Depot in the near future. Companies are scrambling to find new sources with a very limited supply of these materials and they are not renewable. Science goes forward in spite of the resistance of some environmental or health and safety groups. I am told if penicillin would try and be released today it could not pass the tough criteria of the Federal Food and Drug Administration … So, does all the good a drug or product brings to mankind warrant the overzealous groups that try and limit their introduction or use? I guess we'll never know. I recently read a report that, just in the USA, automobiles cause over 116 deaths per day and of course if we look at pollution from emissions and the "speculation" of human-caused climate change, the automobile is probably the single most dangerous invention ever created by man … however, I don't think there is a wave of support to ban the automobile around the world! There are many other scientific introductions that have been under siege for safety and health concerns including cell phones, computers, electricity and nuclear energy. For every advancement there is a negative response. Even one of the newest advancements in our industry, the nanodiamond, has come under scrutiny. While we see the tremendous potential for this material (and other "nano" related products), there are those who see a potential danger if science is once again left to its own devices … Would you believe, some people still say there are health concerns from smoking? Bottom line, all technological advancements should be held up to reasonable scrutiny and weighed against potential hazards … My biggest concern, just where should the line be drawn between reasonable and irrational? Now, where did I leave that cigar?

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David L. Edwards

Sincerely,

David L. Edwards, President
Industrial Diamond Association of America

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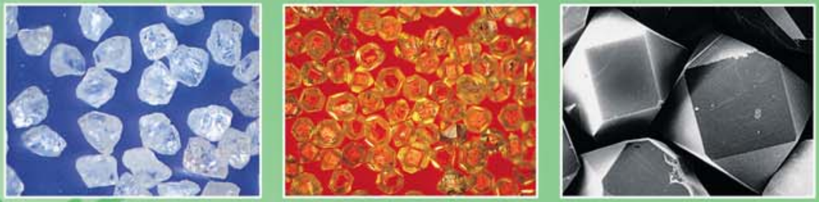

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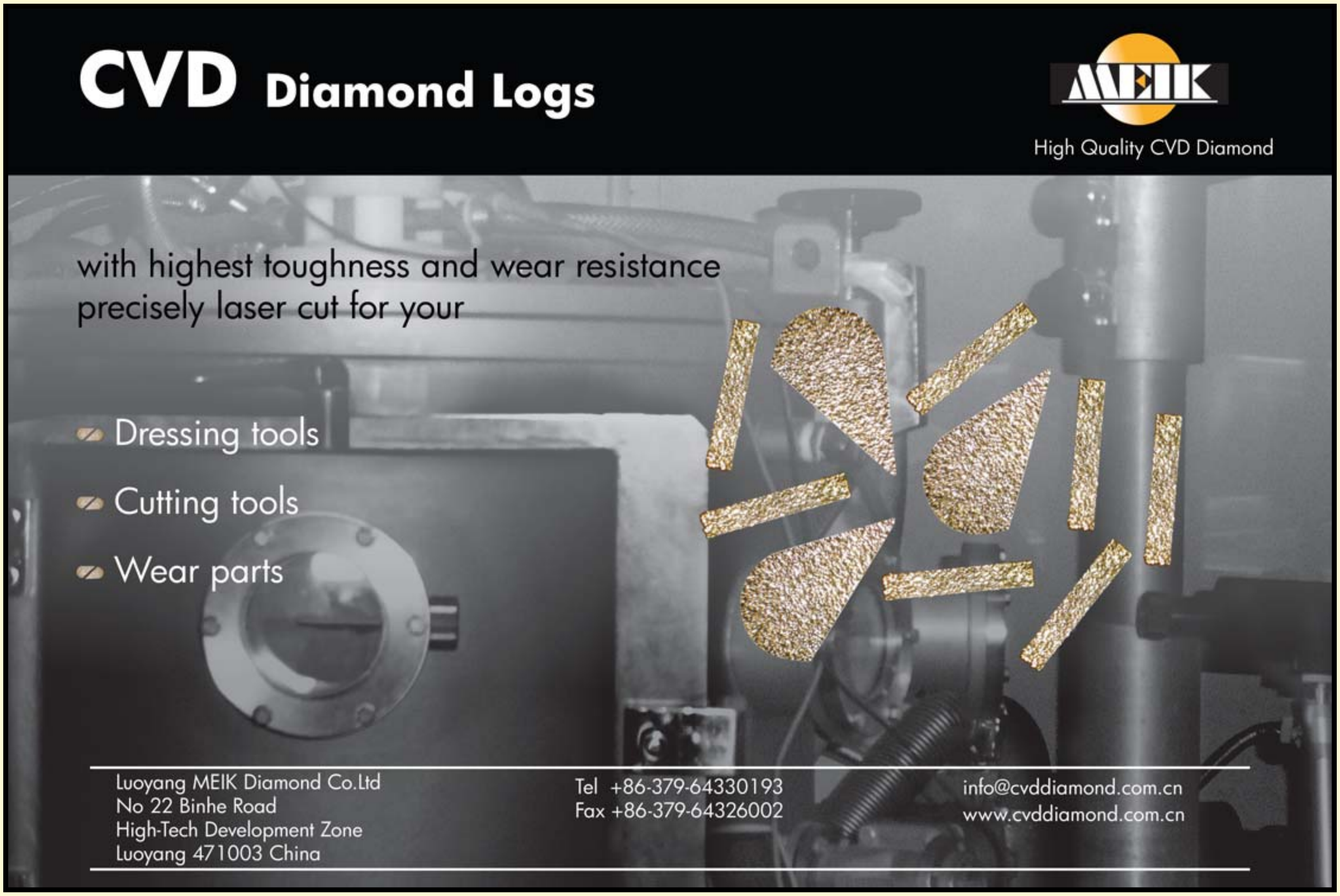
Nanotechnology - Small in Size, Big in Promise …

Terry Kane, Editor

In 1959 Nobel Prize winning physicist Richard Feyman first introduced the concept and theory of the nano, but it took another 15 years before we first heard the term "nanotechnology". All the talk about "nano" was still just theory until the 1980's when the invention of the highpowered microscope enabled scientists to actually see what they were working with on at an atomic scale! Fast-forward three decades … Today nanotechnology is everywhere and turning science fiction into reality in products and industries ranging from medicine to cosmetics and electronics to manufacturing! What is a nano and just how small can it be? A "nano" is a particle size one billionth of a meter, that's smaller than most of us layman can easily comprehend. According to William Hofmeister of the University of Tennessee, if a centimeter was represented by a football field, a nanometer would be the width of a human hair lying on that field! Why is the field of nanotechnology so important? Simply stated, it's the big things these tiny creations can do. They can be structured into specific sizes, shapes and compositions to suit literally any application. Manufacturers are rushing to use nanomaterial to increase the strength, capability, versatility, value or taste of a product. For example:

- Nanosilver, an odor-fighting, bacteria-killing material is now keeping clothing odor free
- Carbon nanotubes are stronger than steel at only a fraction of the weight that for use in countless industrial applications including the new superhard and ultra-light materials
- Silicon chips built with nanotechnology and not much bigger than a period on this page, have been able to store tremendous amounts of data
- Food can now be grown with nanotechnology to improve flavor and reduce spoilage
- Nanodiamonds have been successfully used in motor oil to imbed in moving parts to reduce friction and increase the life of critical components
- Nanodiamond coated with cancer-killing drugs have been successfully injected to destroy cancer tumors

These are just a few products and applications of the more than ten thousand currently reported on the market. It is easy to see why science has embraced and led the way in heralding this new technology. The term "nano" has gained such notoriety that many products without any real nanotechnology are still being promoted as "nano-something" just to bilk the public into thinking they are the latest and greatest new items on the market. However, as with most new technology, there is also an underlying layer of caution. Many fear that there are potential ramifications that loom if science goes forward without a system of checks and balances to protect public health and ultimately the environment itself. Due to the small size of nanomaterials they can become a health hazard when they come in contact with the skin, are breathed into the lungs or are digested or consumed as food and drink treated with nano-processes. Nanomaterials can easily pass beyond the human body's protective systems and this alone has caused unrest among health and safety experts. The Federal Food and Drug Administration has already put groups in place to oversee nanoproduct uses and protect public health. This is a good thing, but the potential boon to mankind from most of these nano-applications will be a driving force to keep this new technology moving forward. With nanotechnology, science is working with the smallest of particles and the biggest promise to come along in quite a while!



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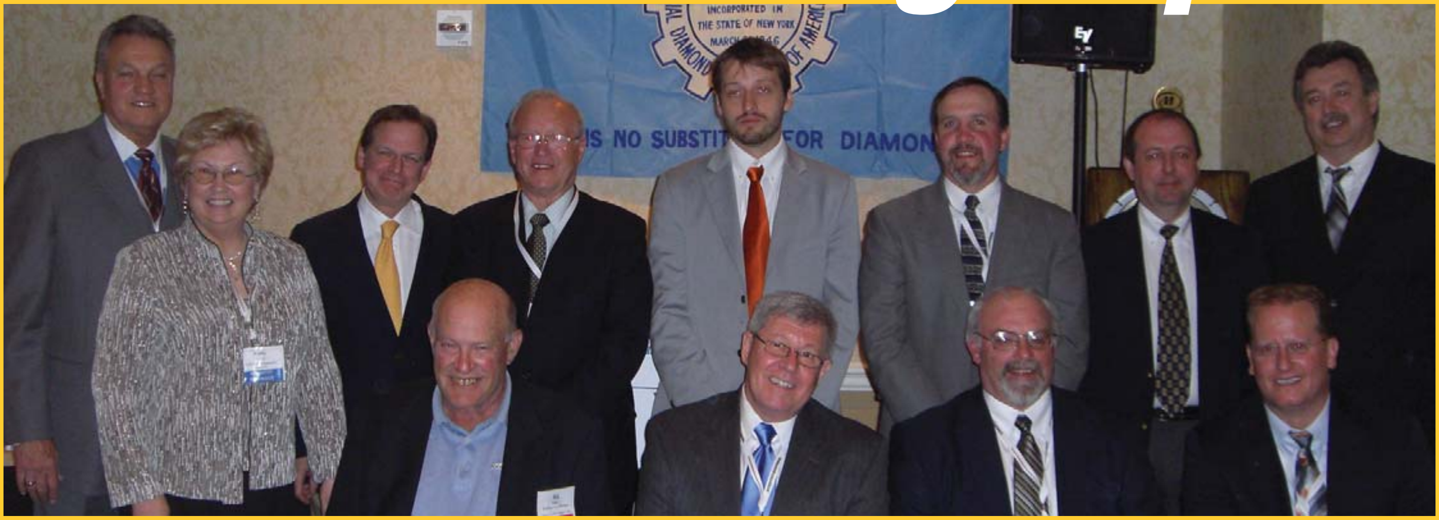
2010 Industrial Diamond Association of America

Annual Meeting Report



THE BOARD OF DIRECTORS AND MANAGEMENT TEAM FOR THE IDA 2010 WAS INTRODUCED

Standing L to R: Executive Director Terry Kane ■ Business Manager Kathy Kane ■ Directors: Jay K. R. Lunzer, Lunzer Inc. ■ Keith Reckling, National Research Co. ■ David Spelbrink, Lieber & Solow, Co. ■ Troy Heuermann 3M Abrasive Systems Division ■ Joe Connolly, Element 6 ■ Scott Reis, Vollmer of America Corp. ■ *Seated L to R:* Secretary/Treasurer Edward Galen, Cinetic Landis Corp-CITCO Products ■ Past President Ion Benea, PhD, Engis Corporation ■ President David Edwards, Action Superabrasive Products ■ Vice President R. Christian Winkel, Worldwide Superabrasives ■ *Not pictured Director:* David Simpson, Sumitomo Electric Carbide Material Group. Everyone wished them well and thanked them for their dedication and commitment.

The **64TH IDA ANNUAL MEETING** was held this year in Columbus Ohio and we are happy to report the attendance was up from previous years and everyone reported positive results for the first part of 2010 with projected improvement throughout 2010 and 2011. There was a new air of confidence and most attendees reported they felt this meeting was important to their businesses as the only time they get to meet with each other at a venue such as this. Attendees were very impressed with the diversity and quality of speakers and freely interacted with speakers throughout the meeting. This year we welcomed 6 new members to the IDA, Bogimac Nv-Sa, Duralor, LLC, Iljin USA, Inc., Radiac Abrasives, Inc., Standard Die & Fabricating Inc. and Hoffman Diamond Products, Inc. The formal program offered a wide range of useful and educational presentations. One of our featured speakers was Fred Schottman, Director of the US International Trade Commission. He addressed our member's issues of improper import/export reports for products in this industry due to the Harmonization Code inconsistency. We discussed ways to correct this problem. Our much-requested speaker, Gina Martin Adams from Wells Fargo Securities once again gave us an excellent forecast, indicating that the industrial side is her favorite for the strongest showing in 2010 and 2011. We also had excellent presentations from Dr Malshe at Duralor on nanocomposite coatings and Keith Reckling from National Research spoke about the industry, where we started, our past innovators and where we are going! Philppe van Bogaert from Bogimac introduced us to his company and their work on mesh abrasives test equipment. Members wanted to see some additional work and asked that he give a paper on his work at **INTERTECH 2011**. We also had two helpful and educational talks from David Annis of Merfield & Shine on considerations and procedures for any merger or acquisition and Rich Klempay took us through the introductory features of setting up a social network for business and personal use. The membership honored Ion Benea for his work as a Director and Officer over the Past few years and also presented an award to Mike Mustin in recognition of his service as a Director. Ion also presented the "President's Award" to Andre Spelbrink for his dedication and longtime service to the Association.

Invisible Diamonds, Diamond at the Nanoscale

By RON ABRAMSHE PhD.
Nano Diamond Products, Shannon Ireland

HALL ANVILS AND CYLINDER CIRCA 1955

Since the early 1900's chemists, physicists and industrialists have had a need for a material that was multifaceted. Diamond is one of those materials that can be beneficial in many ways. From jewelry to machinery to medicine are areas where diamond is beneficial. In the last five to seven years diamond has taken a new form. Its size has decreased from centimeters to millimeters to microns and now to nanometers. Nanometer sized diamond in low concentrations is invisible to the naked eye. With respect to diamond and all its forms, and there are two basic forms, monocrystalline and polycrystalline. This article will speak to the polycrystalline form. The following is a short background of synthetic diamond.

PRINCIPLES OF SYNTHESIS

Diamond and graphite are different forms of crystalline graphite. It was widely believed at the beginning of the twentieth century from geological studies that diamonds were formed very deep in the earth where both temperature and pressures were very high. From the third law of thermodynamics as proposed by Nernst in 1906 it was possible to make the necessary calculations to reach proper equilibrium for crystalline graphite to convert to Diamond. From that point there was a slow but steady progression of individuals who theorized the estimates of the temperature, pressure curve for conversion. Berman and Simon calculated a full conversion line of graphite to diamond in 1955 using reliable data for the lower limits of conversion and subsequently the higher regions of conversion. This is deemed important because the curve suggests that synthetic diamond could be converted at room temperature with high pressures. However synthetic diamond is not thermodynamically stable at room temperature even though they do not convert back to graphite at room temperature. This is because carbon-to-carbon bonds, which require a great deal of energy to break apart, hold the atoms of both forms of carbon together. The required energy on the average is 1010 Newton Meters-2 for sized diamond at 35/40 Mesh. The stability region of diamond synthesis is above 1,800 degrees Kelvin at pressures exceeding 60 kbar. The pressures and temperatures were initially obtained by a type of press developed by Bridgman who made a series of presses and experiments in several failed attempts to synthesize diamond. A later press, which is described by H.T. Hall, is one where a reaction chamber is surrounded by cylindrical electrical heaters that in turn are surrounded by a ceramic cylinder that acts as an insulation barrier. This cylinder is then compressed between tungsten carbide anvils. The cylinder is then encapsulated in an annulus of tungsten Hall Anvils and Cylinder circa 1955 carbide, which is further constrained by steel "belts". One of the most critical features of this type of press is the gasket at the top of the cylinders. This criticality stems from the fact that the gasket materials must withstand the pressure and heat generated by the anvils and must be able to transmit electric current though the internal capsule containing graphite and catalyst.

POLYCRYSTALLINE DIAMOND

The DuPont Company in the 1960's was looking for new ways to use their explosive products. They calculated that one could decrease the process time of making diamond with an explosive shock wave. The pressure and temperatures could be achieved and exceeded. A problem with this method was how to control the reversible reaction due to the high energy required by the explosive mixture. They uniquely used a copper core within their explosive device to cool the reaction after the synthesis of diamond.

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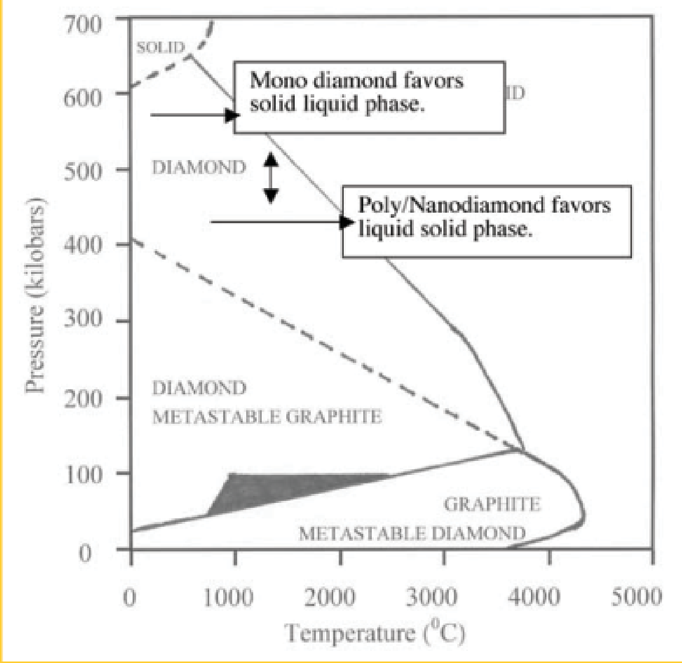
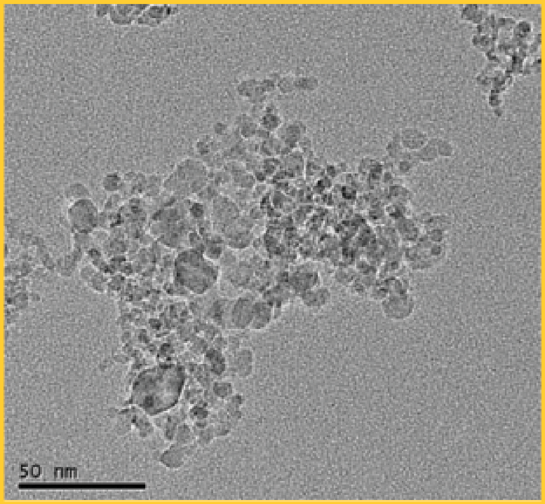
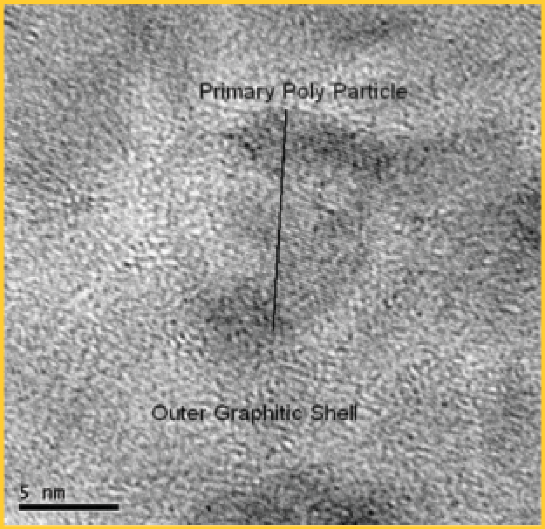


BERMAN-SIMON Properties & Application of Diamond, 1955



Primary Particles Forming UDD Clusters



UDD Particle Surrounded by Graphite Outer Core

The process methodology to synthesize poly diamond is to use crystalline graphite and catalyst. This mixture is packed around a copper tube. This is encased in a stainless steel tube that is encased in a hardened steel tube packed with explosives. The tubes are then projected at a target. Upon striking the target the resultant explosion rapidly converts the graphitic carbon to diamond. Because of the rapid cooling due to the copper core conversion to monocrystalline diamond is stunted and a resultant polycrystalline crystal substructure is formed. The crystallite sizes of the poly crystallites are between 22 and 66 angstroms. Above 66 angstroms the poly-diamond begins to loose its identity as a polycrystalline diamond. Above 108 angstroms it acts much like monocrystalline diamond.

DEFINITIONS OF THE UDD SPECIES OF DIAMOND

- Nanoparticles are any material consisting of grains of particle sizes that are 1 to 100 nanometers in size. These materials would belong to the nanostructure family.
- Primary particle is defined as the base particle that comprises the larger particle in the aggregate. Much like atoms forming molecules, molecules forming substances, substances forming things, e.g. Carbon and hydrogen atoms (Primary Particles) forming long chained hydrocarbons linked together to form crude oil.
- Secondary Particle is defined as the aggregate of the primary particles that are put together in an ordered fashion to form a cohesive part. A UDD cluster can be considered the secondary particle.
- Synthesis Process

Nanodiamond is produced by the detonation of an explosive mixture in an oxygen deficient atmosphere. Nanodiamond has undergone a general shock loading, meaning rapid rise in pressure and temperature from the explosive process. A condition of 30 GPa at 1,000 to 2,300 deg. C. is the general form of production. The result produces thermodynamically stable diamond (carbon) powder. These diamond powders contain agglomerates of 50 nm to 5 um. These agglomerates contain individual crystallites of 2 – 7 nm. A small fraction of these crystallites can be up to 10 to 50 nm crystals.

PROCESSING PROCESS

The recovery of these nanodiamond particles from the percent of explosive detonation requires treatment with reducing and oxidizing chemicals. Combinations of Alkalis and Mineral Acids are used separately in conjunction with heat. This process is necessary to remove metallic, physically adsorbed and chemically absorbed Explosive residue. The approximate yield of useable nanodiamond is roughly 90 – 97%. The 3 – 10% of removed undesirable material consists of 80 – 89% total carbon and 2 – 8% C-O, C=O.

THE PRODUCT

UDD powders contain both primary particles and secondary particles. The primary particles have crystallite sizes on the average of 4 nm and range from 2 – 7nm. The secondary particles are clusters of the primary particles with an outer coating of graphite, graphene and other forms of carbons as carbon onions and tubes as well as some quasi-amorphous carbon. The following is an effort to distinguish some differences in nanodiamond-particles. Nano-diamond particles, each the size of a small virus and less than 1,000 times the thickness of a human hair are made from carbon.

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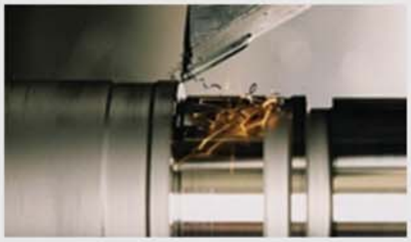

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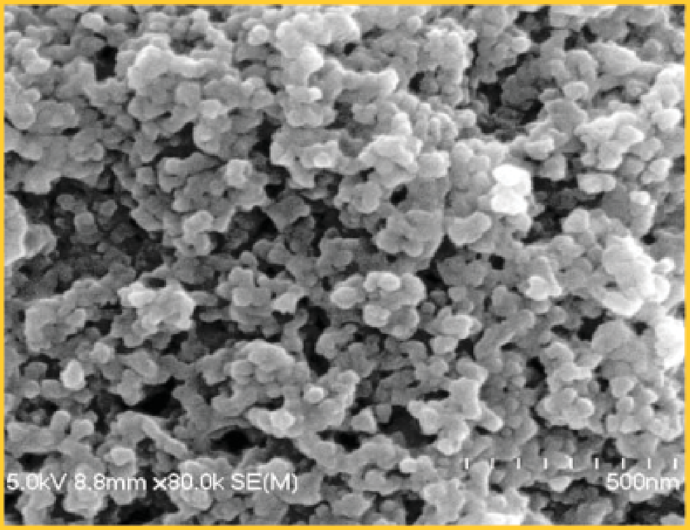


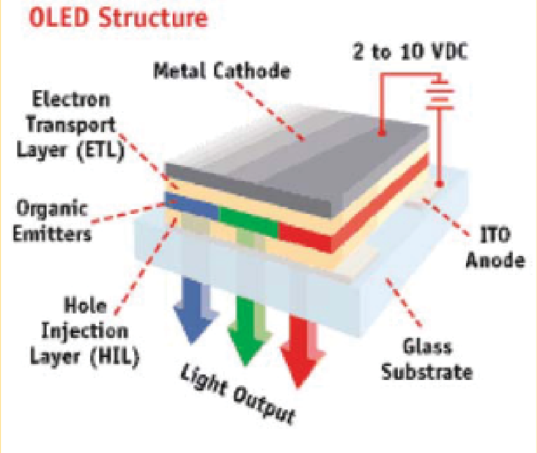
Example of Nanodiamond Clusters in a Dried Powder

NANOPARTICLES

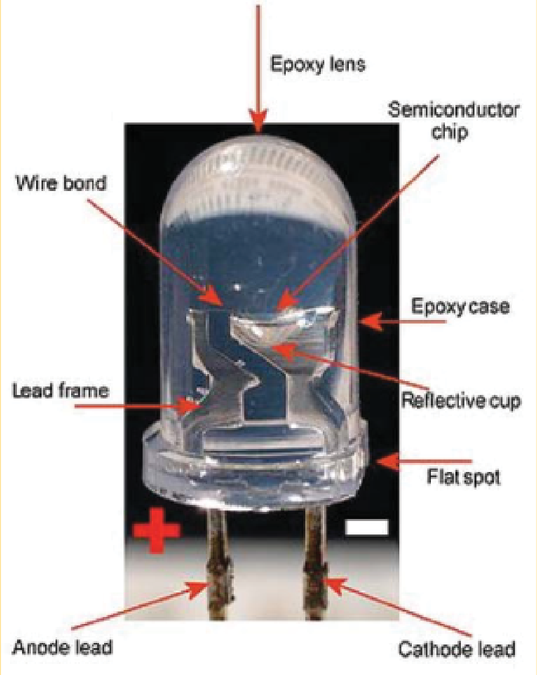
The manufacture of polycrystalline diamond powders based on the explosive method of nanodiamond is of interest not only from an intellectual perspective or from the theory of sintering but more importantly on this material's application. From an intellectual perspective, nano-particles open new vistas in micro machines, medical applications and in new frontiers of industries as electronics, coatings and optics.

EXAMPLES OF WHERE NANODIAMOND IS USED

The composites noted in the charts have been tested for Izod impact strength. At 0.5w% nanodiamond addition the impact strength increased by 30%. Standard Brinell hardness values were obtained.



Super Polishing Will Increase the Light Output at the Same Power Level

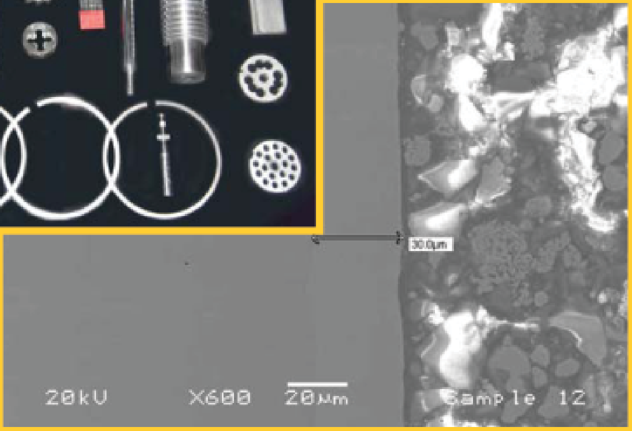


A Higher Polished Surface Will Emit More Light for the Same Energy Output

R Plane Sapphire for Optical Applications and C Plane Sapphire for EPI Ready Wafer Polishing

Super Polishing of Silicon on Sapphire, LED Application

Parts That Have Been Plated with Nanodiamond for Practical Applications



Example of Nanodiamond Deposition on Tool Steel, 30um Diamond Coating, and Hardness is Increased 3.5X (Vickers)

SOME USES OF NANODIAMOND

Nanodiamond is used in any application where super finishes are required as in the polishing of optics that is used in telescopes, laser windows and extraterrestrial vehicles for space exploration. We are also seeing a next generation of diamond cutting tools with a more uniform and ordered microstructure. Nanodiamond can be used to increase the wear resistance of drills and cutting tools can be made sharper and produce better finishes while lasting longer when machining tough metallic objects like Titanium or deep oil and gas exploration. Nanodiamond can be used in densification of other materials made from aluminum, boron nitride, boron carbide and magnesium oxide/niobium oxide combinations. Here the applications become almost unlimited. Some examples would be a fully dense but lightweight armor or as filler for cermets in the structural ceramics industry. Nanodiamond applied in fixed polishing applications as in polishing films and polishing pads for fiber optics applications increases the useable area of Silicon Carbide wafers by removing defects. In the field of medicine, nanodiamond has been used as a carrier (delivery system) of medications for treating Tumors. Nanodiamond is a biocompatible material. Because of their nano-size and ability to "carry" medications into the cell without inflammation. Nanodiamond is becoming a promising new material in medical treatments. There are advanced Chemical Mechanical Planarization applications for polishing sapphire, SiC, GaAs, GaN and other compound semiconductors to un-precedent levels of precision, while improving surface integrity (i.e. removing sub-surface damage, cracks or micro-cracks) and obtaining surface finishes of less than 2 nm on various A, C, M and R plane sapphire for optical or electronic applications. The same finishes can be obtained on Silicon Carbide wafers for IC memory devices. Nanodiamond can be used in electrolytic and electroless plating applications with very little modification to the process. It has been suggested that the effect of ultra dispersed diamonds resulted in hardness, strength and fine structure with respect to current density and diamonds concentration in the electrolyte. Potential application of the coating is sliding bearings, insulators, medical appliances and aerospace parts. It has been shown that small additions of functionalized nanodiamond to a polymer matrix can lead to positive modifications leading to essential improvements in rheological, mechanical and tribological characteristics. ■

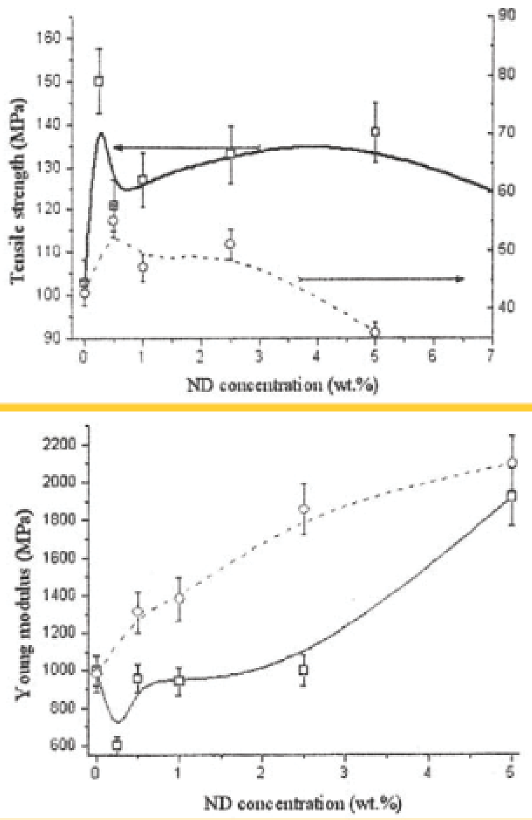


FIGURE 3: Tensile properties of PSF/ND (■) and SAN/ND (●) nanocomposites vs. nanoparticle content (composites obtained via melt-mixing in "spurt" regine).

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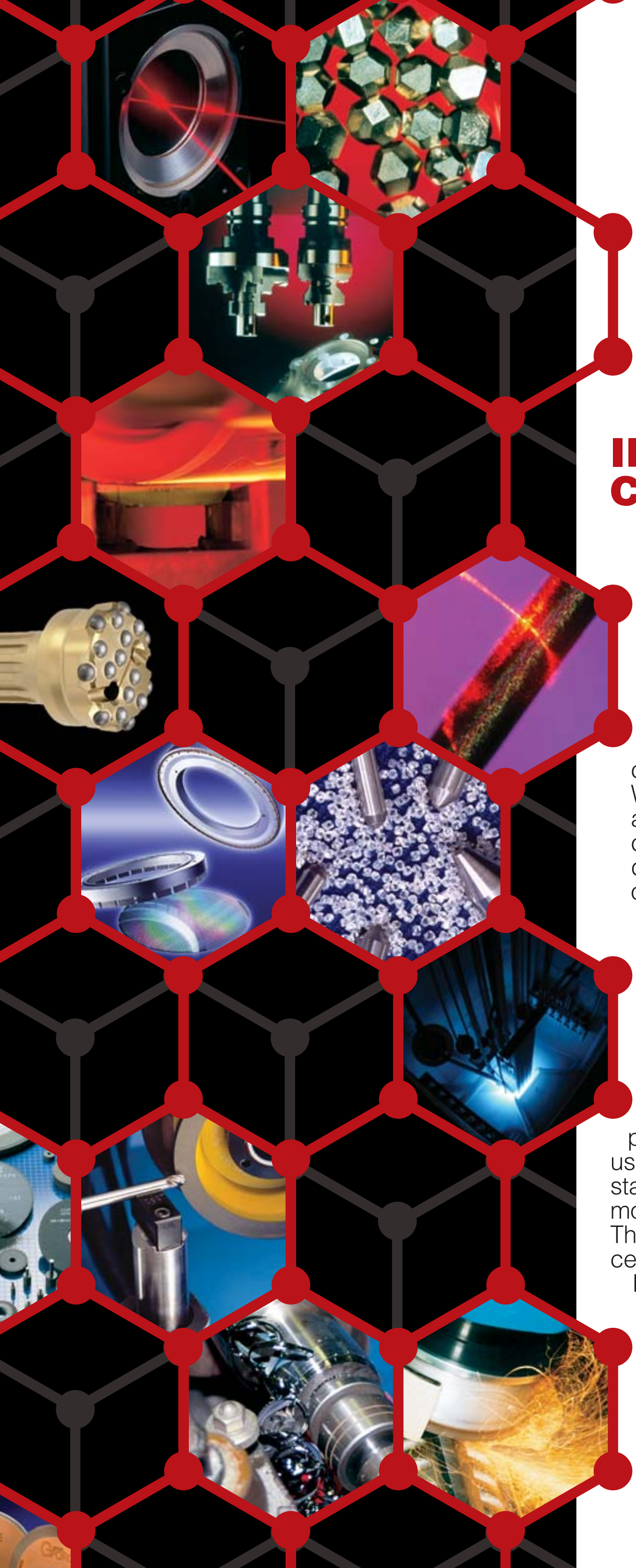

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  - Gears
  - Wheels
  - Transmissions
  - Engines

CONSTRUCTION/ HIGHWAY
- Concrete Aggregates & Variables
- Highway/Runway
  – Grinding & Grooving
  – Bridge Repair
- Renovation
- Block Grinding
- Polishing

ELECTRONICS
- Disc Texturing
- Wafer Mfg.
  - Polishing
  - Optic Windows
  - Semiconductors
  - Heat Sinks

EMERGING TECHNOLOGY
- CVD Diamond
- Nanodiamond
- New Crystals
- Coatings

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- Lens Generation
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MACHINE TOOLS
- Development
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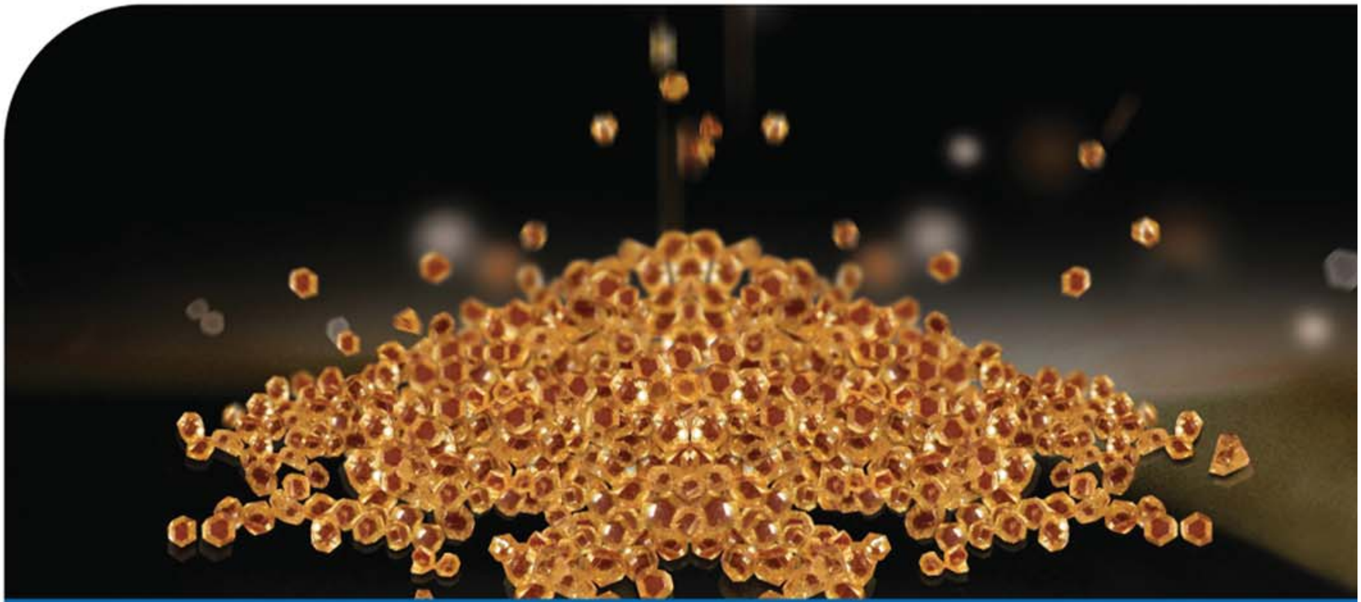

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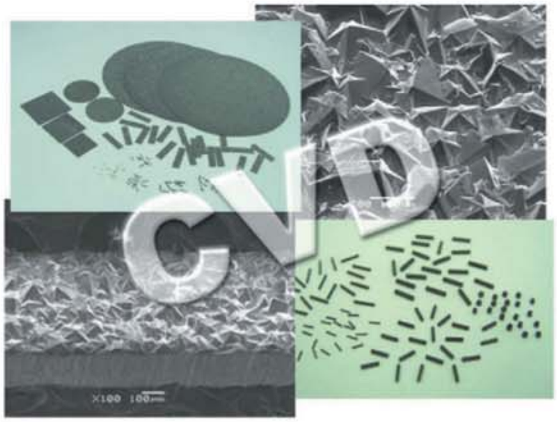

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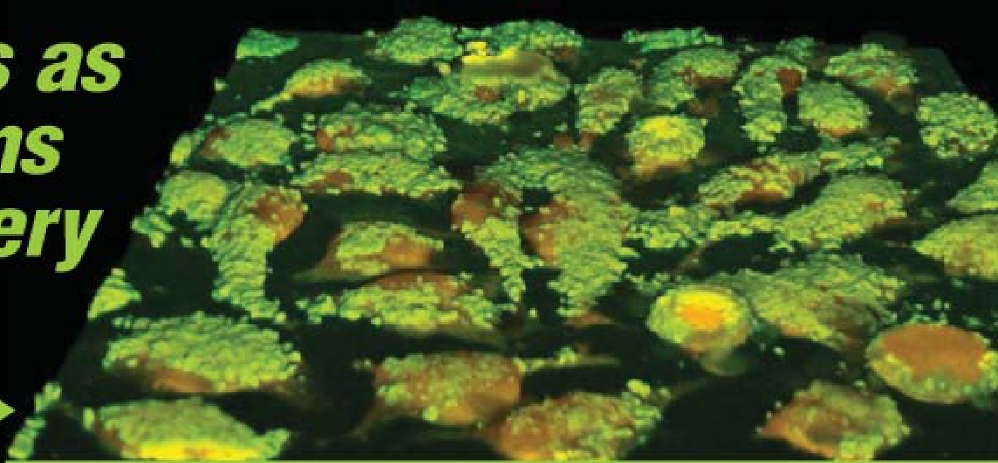
Nanodiamonds as Novel Platforms for Drug Delivery and Imaging



Nanodiamonds Interacting with Cells ▶

DEAN HO, Ph.D.
Departments of Biomedical and Mechanical Engineering Robert H. Lurie Comprehensive Cancer Center Northwestern University
d-ho@northwestern.edu

Nanodiamonds have recently made important strides as powerful platforms for the delivery of a broad range of therapeutics as well as imaging agents for medicine. Their surfaces are highly unique, with electrostatic properties that promote extremely tight water and therapeutic compound binding to the nanodiamond surface. This potent interaction makes nanodiamonds applicable towards enhanced drug delivery and imaging. Nanodiamonds that are functionalized with carboxyl groups are also scalably produced via facile processing techniques including acid washing, ultrasonication, and ball milling. The availability of surface-bound carboxyl groups serves as the foundation for the properties that make nanodiamonds a promising nanomaterial for medical use. These properties include enhanced nanodiamond solubility in water, and the opportunity to covalently bind therapeutic, imaging, or other chemical compounds that can promote solubility, delivery efficacy, etc., against the surface of the diamond. Exciting recent developments have harnessed these attributes towards the introduction of nanodiamond-based drug delivery that has since developed into an international effort towards the establishment of this burgeoning field.

Nanodiamond-Small Molecule Delivery

Nanodiamond-Small Molecule Delivery: Initial studies introduced a unique nanodiamond-chemotherapeutic (nanodiamond-Doxorubicin) complex with remarkably potent binding efficiency to promote highly sustained drug release towards the treatment of cancer. This structure was examined as a stand-alone nanoparticle delivery system for systemic injection (Figure 1)[1], a microfilm-based device for localized delivery [2], a single-cell injectable particle for localization studies [3], self-assembled thin film for anti-inflammatory delivery [4], as well as the binding and elution of water-insoluble drug compounds [5]. Furthermore, the nanodiamond material itself was shown to highly biocompatible at the genetic level, where inflammatory cytokine expression (e.g. IL-6, TNF-alpha, iNOS, etc.) was not activated following nanodiamond exposure [1-5].

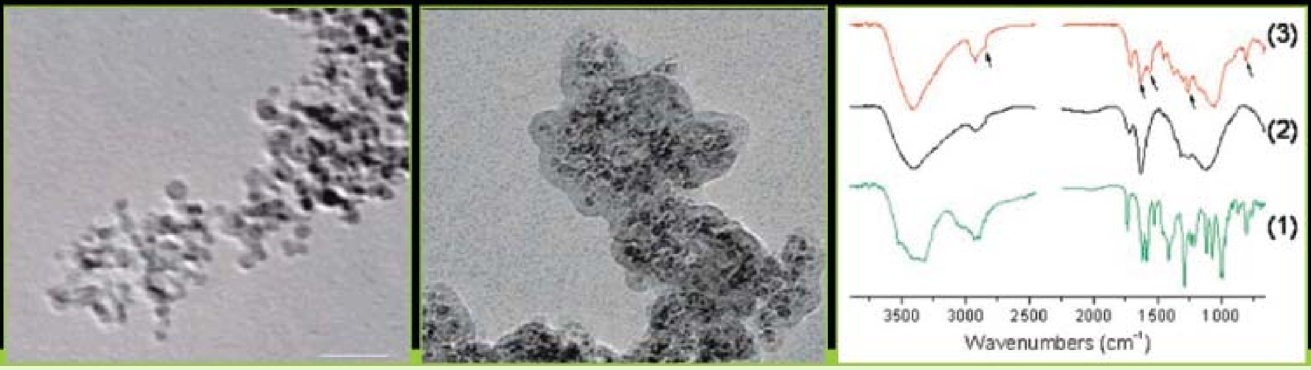
Nanodiamond-Insulin Complexes for Wound Healing Applications

In addition to the delivery of small molecules, the concept of therapeutic protein delivery (insulin) using nanodiamonds with pH-dependent release properties for enhanced treatment specificity was also recently studied [6]. Insulin is being explored as a wound/severe burn-healing agent because of its potential for promoting re-vascularization following injury, and is also being explored as a potent anti-infection agent. Using cellular viability and gene expression assays, this study realized a nanodiamond-insulin complex capable of sustained insulin release in alkaline conditions (present during bacterial infection of wounds), further expanding the impact of the nanodiamond material.

Nanodiamond-Mediated Gene Delivery

The delivery of DNA is being explored as a strategy to treat several major diseases that include cancer, heart disease, diabetes, and others. Non-viral gene delivery can be challenged by the observation that delivery is often efficient and toxic, or inefficient and non-toxic. Several commercial strategies such as polyethylenimine (PEI) in both high and low molecular wrights have been explored, yielding promising efficacy or biocompatibility properties. To further integrate enhanced efficacy into a non-viral, nanoparticle-based gene delivery vehicle, a recent study by Zhang and colleagues developed an nanodiamond-polyethylenimine800 (PEI800) complex that was capable of boosting gene delivery efficacy 70 times while simultaneously maintaining the non-toxicity of PEI800, thereby realizing a highly efficient and safe material (Figure 2)[7].

Figure 1. **The characterization of nanodiamonds (a-uncoated, b-drug coated) for cancer drug delivery is shown via transmission electron microscopy. Confirmation of drug binding is demonstrated via Fourier transform infrared spectroscopy (FTIR) [1].**



Nanodiamond-Based MRI Imaging Agents

Nanodiamond-Based MRI Imaging Agents: nanodiamonds have previously been explored as promising biological labels for cellular and tissue studies [8-13]. Transitioning the nanodiamond towards clinical applications has inspired the integration of current methodologies such as magnetic resonance imaging (MRI) with novel nanomaterials to increase imaging contrast while potentially minimizing toxicity associated with the current agents that are employed. Recent developments have included the synthesis of a nanodiamond-Gd (III) magnetic resonance imaging agent that was capable of producing among the highest relaxivity values ever reported (including a 12 times enhancement over clinical agents). Amine-functionalized Gd (III) agents were covalently bound to the nanodiamond surface, and by harnessing the unique water-binding properties of the nanodiamond surface, this work generated a complex with an MR signal of unprecedented efficacy and maintained biocompatibility as confirmed through cellular incubation assays. This technology may make it possible to drastically reduce the amount of agent injected while simultaneously producing high contrast images during diagnosis and therapy [14].

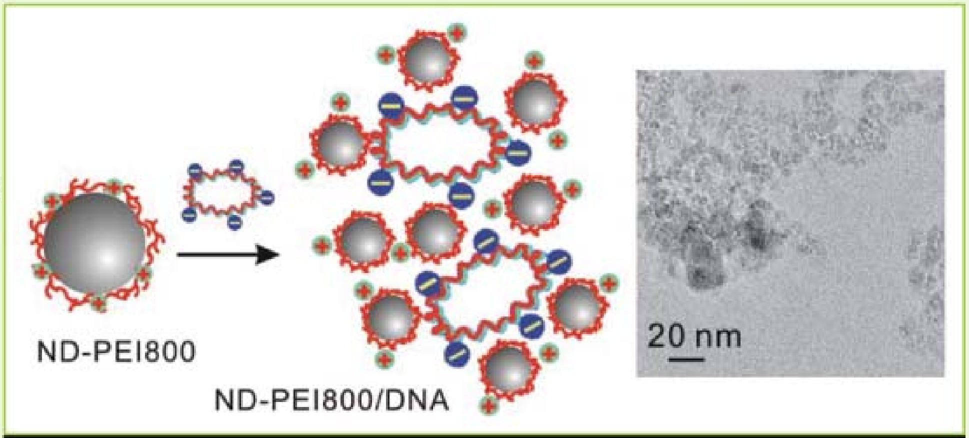


Figure 2. **Nanodiamonds (ND) can serve as effective gene delivery agents, where polymer functionalization of the material surface can enhance delivery efficacy while preserving platform safety [7].**

Impact

Impact: These studies have revealed the broad applicability of nanodiamond platforms for therapeutic release and medical imaging applications as nanodiamond-modified therapeutic and imaging compounds have displayed significant efficacy enhancements and biocompatibility. A broad spectrum of unmet needs in medicine is driving the development of novel materials possessing the properties required to successfully address current challenges. From cancer to wound healing, nanodiamonds serve as a promising platform to make a significant impact in how nanomedicine can transform and improve the way that patients are treated. ■

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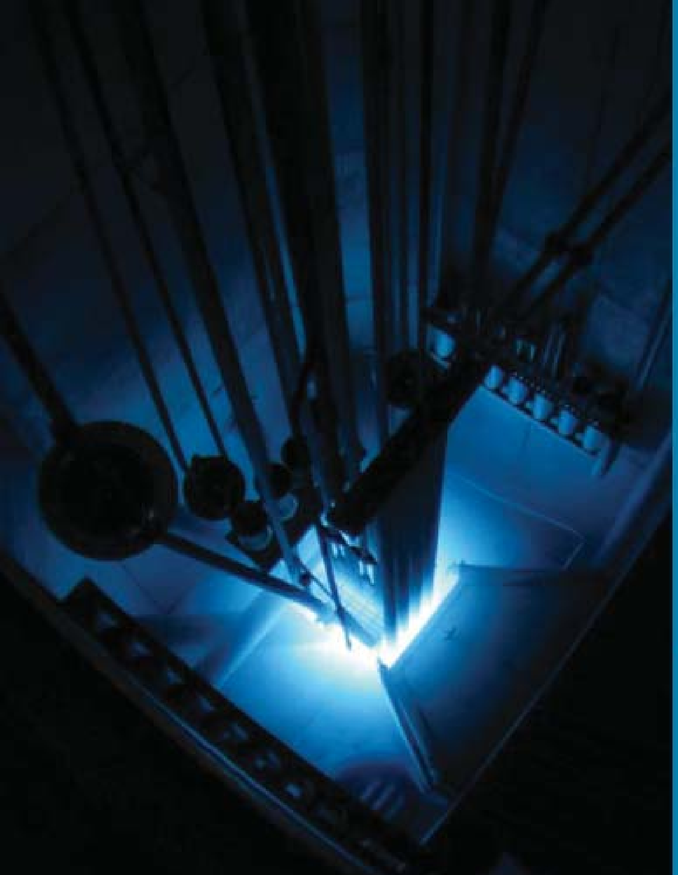

Applications of Advanced Nano Engineered Lubricants Teamed Up with Bio-Inspired Surfaces of Superabrasive cBN-TiN Composite Coating and for Minimum Quantity Lubrication (MQL) Grinding

By: Parash Kalita[1], Wenping Jiang[2], Albert Shih[3], and Ajay P. Malshe*[1,2]

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[2] NanoMech LLC, Springdale, AR

[3] Mechanical Engineering Department, University of Michigan, Ann Arbor, MI

Photograph courtesy of National Science Foundation - The PULSTAR reactor produces the world's most intense low-energy positron beam. Through the use of this National Science Foundation Major Research Instrumentation program-funded instrument, researchers will have better measurements of a material's porosity to improve the development of nano materials and nanotechnology.

Effective lubrication is an area of significant interest for advancing manufacturing efficiency and productivity. Molybdenum disulphide (MoS_2) micro and nanoparticles are known to possess exceptional tribological and lubricating properties. In two unique examples, these solid lubricant particles were applied to (1) the surfaces of cBN-TiN composite coatings in a form of a coating and (2) as an additive to liquid lubricant for minimum quantity lubrication (MQL) machining using alumina grinding wheels. In the first part, a cBN-TiN hard composite coating was surface textured and resembled to that of lotus leaf. The "valleys" embossed inside the biomimetic surface structure served as nano-/micro-reservoirs of solid lubricant particles of MoS_2. The tribological test results showed a significantly lower coefficient of friction for superabrasive cBN-TiN coatings with MoS_2. In the second part of this research, the tribological behavior and performance of novel MoS_2 nanoparticles based grinding fluids was evaluated in MQL grinding of cast iron. The results showed that lubricants with novel MoS_2 nanoparticles significantly reduces the tangential grinding force and friction between the wear flats and the workpiece, increases G-ratio and improves the overall grinding performance in MQL applications.

Example 1

Bio-Inspired Surface Engineering and Tribology of MoS_2 Over-coated cBN-TiN Composite Coating.

In this research, based on a multi-layered design and surface patterning, a novel bio-inspired self-lubricating surface layer was produced on a cubic boron nitride (cBN) and titanium nitride (TiN) composite superabrasive coating. The coating had a biomimetic surface texture, replicating lotus leaf. The cBN-TiN hard coating was deposited on a cemented tungsten carbide substrate by a hybrid coating technology, i.e., electrostatic spray coating of the nano-/micro-particles of cBN followed by chemical vapor infiltration of a TiN binder phase (published in Finer Points before called, TuffTek® from NanoMech Inc). cBN is a superhard material, and it has very good thermal stability and chemical inertness. The continuous hard TiN phase, combined with the cemented carbide substrate, offers excellent adhesion, toughness and compatibility with cBN. This nano-structured coating layer provides a unique combination of thermal stability, chemical inertness, outstanding wear resistance and high load support capacity. The top surface of the coating layer was textured to give biomimetic morphology by carefully controlling ESC and CVI processing parameters, providing micro-pockets to store lubricants in the form of micro and nano particles. Nano-sub-micron solid lubricant particles of molybdenum disulfide (MoS_2) were then embedded into the micro-nano-scale surface valleys, or micro-nano-reservoirs, through simple but effective tumbling. The bio-inspired surface design could effectively hold solid lubricant particles, and those lubricant particles were expected to be released from the reservoirs to the sliding interface and reduce coefficient of friction during tribological operations, such as extrusion dies, molds, machining, etc.

EXPERIMENTAL DETAILS

Wear-resistant cBN-TiN composite hard coatings were produced by using a hybrid coating technology combining ESC technology and CVI deposition. Sub-micron cBN powder (particle size less than 2 µm) was applied to the grounded substrates as a coating preform by the ESC spray process. In the ESC deposition process the commercially acquired cBN particles were ejected from the spray gun with negative charges. The charged particles followed the electrical field lines toward the grounded substrates and assembled a uniform coating on the substrate surfaces. The ESC-coated samples on the substrates were porous, which allows for infiltration of vapor phase to stabilize and bond the superhard cBN particles. In addition, the ESC-coated cBN particles were only loosely bound to each other and to the substrate by electrostatic forces. To make the deposited coating functional, a follow-up CVI process was used to consolidate the porous cBN preform to form a composite coating. TiN was uniformly infiltrated on the individual cBN particles throughout the depth of the ESC-coated porous layer and the substrate surface. Solid lubricant molybdenum disulfide particles, with an average particle size of 700 nm were encapsulated in the chamber of a tumbler and were tumbled on the cBN-TiN composite coating surfaces with a tumbling period of 45 min. For each tumbling operation, fresh particles were added in the chamber.

RESULTS AND DISCUSSIONS

The as-deposited cBN-TiN wear-resistant coating has a biomimetic surface texture, similar to that of lotus-leaf, as shown in Figure 1a. The rounded protrusions of TiN, with diameters ranging mainly from 5 to 20 µm, but with a few as large as 40 µm, on the coating surface are like epidermal papillae on the surface of a lotus leaf as shown in Figure 1b. Naturally there is a tremendous number of micro-scale surface "valleys" constructed among those protrusions. Surface valleys were filled with solid lubricant particles after the tumbling process. Figure 2 shows the surface morphology of a tumbled cBN-TiN coating surface with MoS_2 nano- micro-particles, where Figure 2b is an enlarged view of the highlighted area in Figure 2a. It is clear that after tumbling MoS_2 particles were trapped in the surface micro-reservoirs of the cBN-TiN coating, and consequently the biomimetic feature of epidermal papillae were sealed by the lubricant particles. EDS results suggested that the whole coating surface was covered by molybdenum disulfide. This implies that besides the trough areas the top surfaces of TiN epidermal papillae were also burnished with MoS_2. Sliding of the tumbled cBN-TiN composite coating against a 440C steel ball resulted in a relatively low coefficient of friction, as indicated in Figure 3. The coefficient of friction started high in the run-in period, with an initial value of $\mu = 0.40$, and that value decreased to about 0.28 when the sliding reached a steady state. After sliding, the wear track was smooth as opposed to the original tumbled surface, with MoS_2 particles recognizable on the track. Further analysis showed that Mo and S peaks dominated the EDS spectra for the chemical analysis on the track, but also there was a significant amount of Fe, C and O. They were transferred from the pin surface and mechanically mixed with MoS_2 particles in the contact region, consistent with the observation of materials transfer and mixing in sliding of other coating systems and metals. It was also seen that the MoS_2 platelets on the wear track were smeared along the sliding direction, and the overall wear track was smoothened after sliding. Further FIB/TEM and STEM/EDS studies on cross-sections of the sliding interface and subsurface confirmed that after sliding the crystalline MoS_2 platelets were reoriented with respect to the sliding direction, i.e., after sliding their basal planes should be parallel to the sliding direction, leading to good lubrication, consistent with observations and discussions from other researchers. EDS line scanning with a nanoprobe in STEM verified that the needle-like particles are MoS_2 displays the overall arrangement of the MoS_2 nano-micro-particles with respect to the sliding direction. The reorientation of MoS_2 platelets induced by sliding process on the wear track reduces the shear strength of the tribolayer, making sliding between the pin and the tribolayer easier. This is responsible for friction reduction during steady state sliding of the tumbled cBN–TiN composite coating. To comparatively evaluate the performance of the MoS_2 over-coated superhard bio-mimetic cBN–TiN composite coatings, a commercially achieved MoS_2 coating deposited by a PVD method, specifically ion beam deposition, on a tool insert substrate was tested with the same sliding conditions. Unexpectedly, the steady state coefficient of friction for PVD MoS_2 coating was similar to that for the tumbled cBN–TiN composite coating.

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Example 2

Performance of Novel MoS_2 Nanoparticles Based Grinding Fluids in Minimum Quantity Lubrication (MQL) Grinding

In material removal operations, the role of grinding process is indispensable, especially in finishing operations that demand close tolerances, for application such as bearings, pin-joints, shafts, etc. To improve the overall grinding performance, a heavy amount of

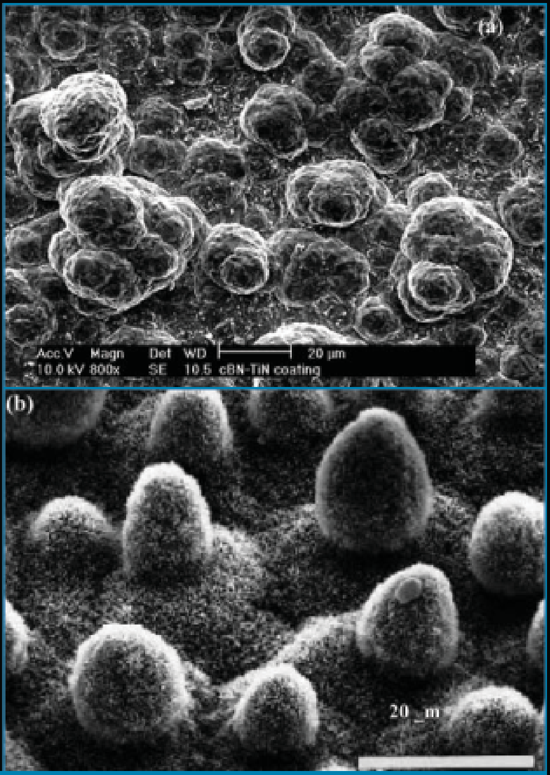

FIGURE 1: *SEM images showing the similarity of surface morphologies of (a) CBN-TiN composite coating and (b) lotus leaf [Barthlott, et al., 1997]*

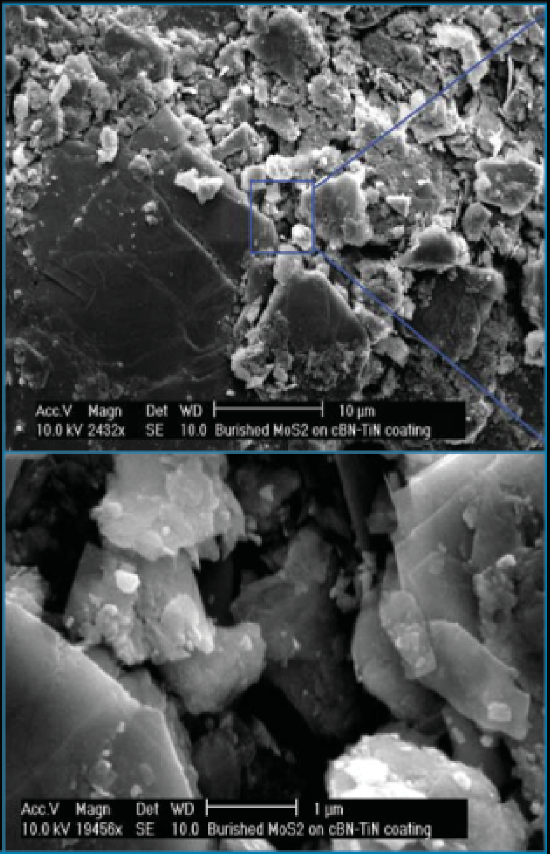
Acc.V Magn Det WD 10 µm
10.0 kV 2432x SE 10.0 Burished MoS2 on cBN-TiN coating
Acc.V Magn Det WD 1 µm
10.0 kV 19456x SE 10.0 Burished MoS2 on cBN-TiN coating

FIGURE 2: *Secondary Electron Micrographs (SEM) showing MoS_2 nano-micro-particles trapped in the surface reservoirs on the CBN-TiN coating after tumbling. Figure 2b is an enlarged view of the highlighted area in Figure 2a.*

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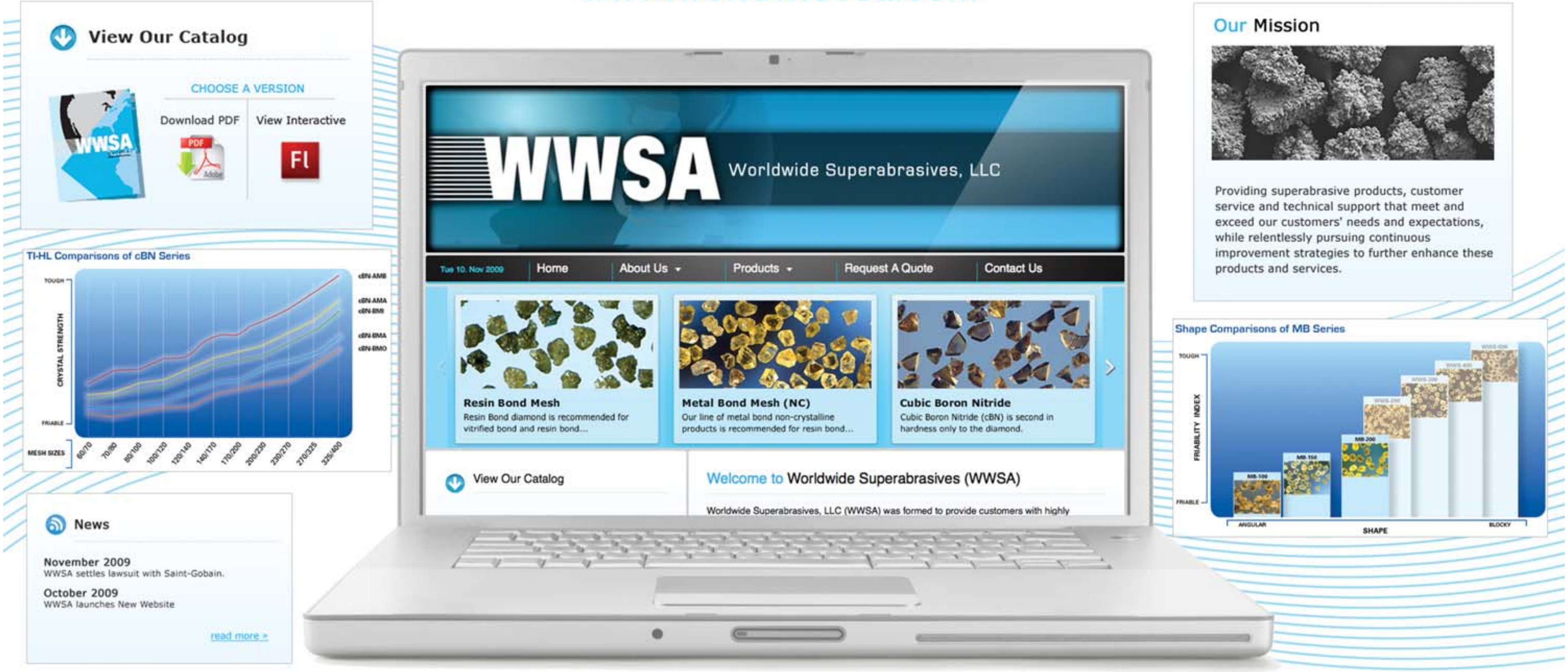

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grinding fluids (coolant) is used. Strict environmental laws on the usage and disposal of these fluids, combined with high recycling costs have generated a need for developing environment friendly, energy saving and cost-effective sustainable grinding fluid alternatives. Under these circumstances, MQL (near dry machining) have become an attractive alternative and need research. MQL refers to the use of minute amount of cutting fluids – typically at a flow rate of 50 to 500 ml/hour – which is about three to four orders of magnitude lower than the amount commonly used in a flood cooling condition.

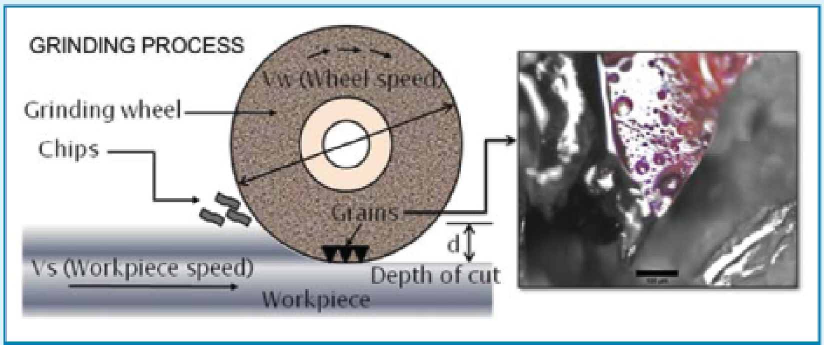

FIGURE 4: *Schematic Illustration of Surface Grinding Process*

Molybdenum disulphide (MoS_2) is a predominant material used as solid lubricant, due to their hexagonal closed pack (HCP) layered structure. MoS_2 in its nano-particulate form have been reported to possess exceptional tribological and lubricating properties under extreme pressure conditions. It is proposed for the first time that nanoparticles of MoS_2 suspended in the grinding fluid could navigate into the grinding wheel–workpiece contact zone and provide significant lubrication and friction reduction, when abrasive grains, for example of alumina, from grinding wheel will plunge and remove the cast iron work-material. To test this hypothesis, the MQL grinding performance of MoS_2 nanoparticles based lubricant additives in three commercially available base oils; namely, paraffin oil, soybean oil and CANMIST oil were compared with that of the three base oils (without MoS_2 nanoparticles) and with that of flood cooling using water based commercial synthetic grinding fluid. The performance comparison was made using key factors, namely, grinding force and grinding wheel wear.

EXPERIMENTAL DETAILS

Grinding Fluids

A nanoparticle-based grinding lubricant additive (now available as product called NanoGlide® from NanoMech Inc.) consists of MoS_2 nanoparticles (<100nm) intercalated with triglyceride chemistry plus emulsifier lecithin (Alcolec). This additive was dispensed in two concentrations, high concentration (20 wt.%) and low concentration (5 wt.%) in three commercially available base oils, namely: paraffin oil (mineral based oil), soybean oil (vegetable based oil) and commercial MQL metal working fluid CANMIST (high purity fatty alcohol based oil, AMCOL Corp.). To prepare the described nano-engineered molybdenum disulphide additive, MoS_2 micro-particles (Alfa Aesar, 98% pure, 3-5 µm average particle size) mixed with triglycerides and emulsifier, was ball milled in SPEX 8000D mixer mills using hardened steel vials. From high-resolution transmission electron microscope (TEM) analysis, it was found that the resultant nano-engineered MoS_2 particles shaped like "elongated coconut" as shown in Figure 5, with an average size of about 70 nm along the major axis and 40 nm along the minor axis.

The nanoparticle design used in the present study consisted of three multi-layers of chemistry at the nanoscale, particularly (1) MoS_2, (2) over-layer of Canola Oil (triglyceride molecules) and (3) lecithin. This lubricant formulation is relatively more environmentally friendly than

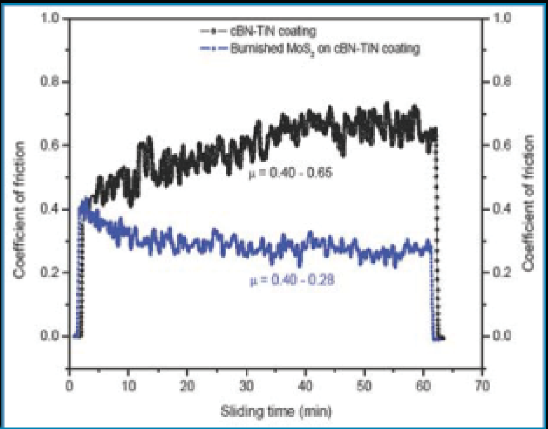

FIGURE 3: *Coefficient of friction vs. time during sliding of 440C stainless steel balls against a cBN-TiN composite coating and burnished MoS_2 on a cBN-TiN coating in vacuum (~10-4 Pa).*

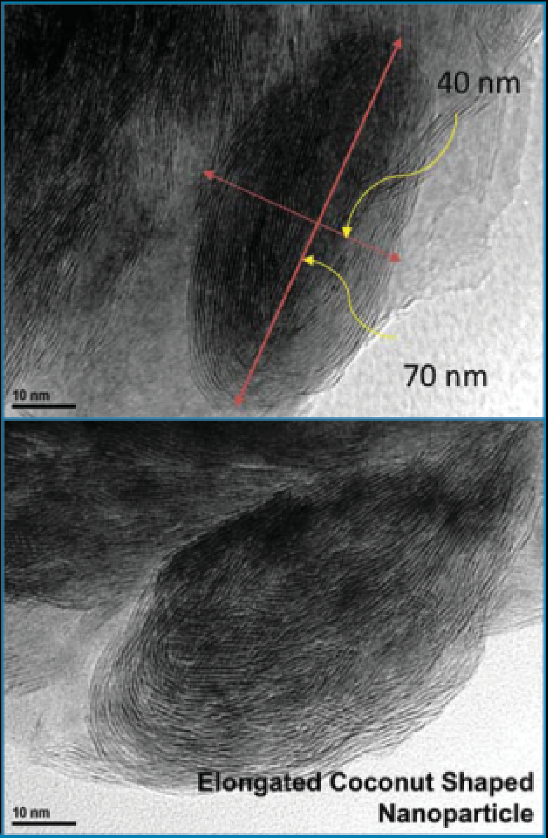

FIGURE 5: *Tem Image of Nanoengineered MoS_2 Particle*

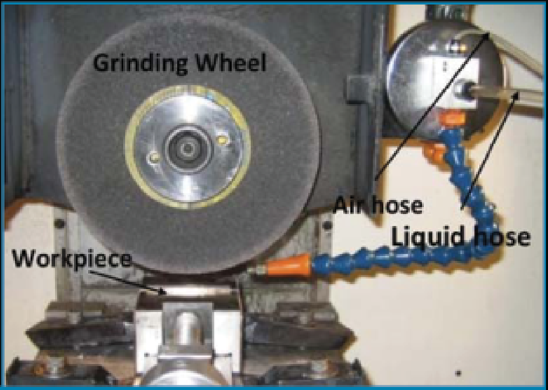

FIGURE 6: *Grinding Parameters*

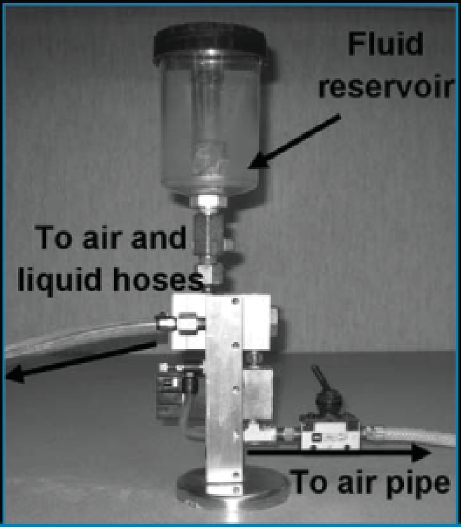

FIGURE 7: *MQL Equipment Setup*

Wheel surface speed (m/s)	30
Depth of cut (µm)	10
Workpiece velocity (mm/min)	2400
Grinding passes	200
Flow rate- MQL (ml/min)	5
Flow rate- Flood (ml/min)	5400

TABLE 1: *Grinding Parameters*

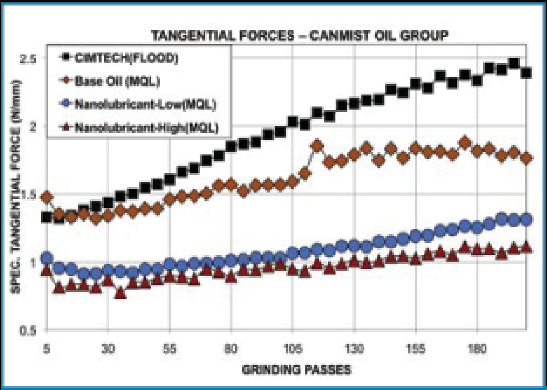

FIGURE 8: *Tangential Grinding Forces vs. Grinding Passes: CANMIST Group*

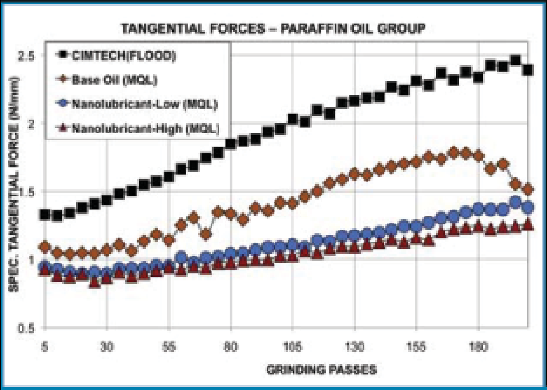

FIGURE 9: *Tangential Grinding Forces vs. Grinding Passes: Paraffin Group*

conventional fluids. MoS_2 is extensively used as solid lubricant in various manufacturing and application sectors using proper safety precautions stated in MSDS (CAS no.1317-33-5). Canola oil and lecithin (emulsifier) are traditionally, environmental and human friendly chemistries used as edible oil and common ingredient of food, respectively.

MQL Grinding Machine

Straight surface plunge grinding experiments (no cross feed) were conducted on an instrumented surface-grinding machine using the setup shown in Figure 6. A vitreous bond aluminum oxide (Al_2O_3) grinding wheel was used. (In future similar experiments will be performed using cBN and diamond bonded grinding wheels, as we believe nanolubricant can aid various grinding wheel and workpiece combinations). The workpiece material was 100-70-02 ductile iron (HRC 50) with a fluid delivery system (Figure 7) supplying a minimum quantity of lubricant during the tests.

EXPERIMENTAL RESULTS & DISCUSSIONS

Measurement of Grinding Forces

The specific tangential grinding forces vs. grinding passes for all the grinding fluids are shown in Figures 8 to 10. MQL grinding with pure base oils (without nanoparticle-based lubricant) generate lower tangential forces than flood cooling as shown in Figures 8, 9 and 10. This clearly demonstrates that lubricant delivered using this MQL system was able penetrate into the region of contact between the grinding wheel and the workpiece more effectively than flood cooling. In Figures 8 and 9, the lubricants with above described nanoparticle-based lubricant showed significant improvement in grinding performance by lowering the grinding forces and the force ratio. CANMIST and paraffin oils with nanoparticle-based lubricant significantly reduced the grinding forces as well as the friction between the wear flats and the workpiece as compared to the base fluids. This significant reduction can be attributed to the enhanced penetration of MoS_2 nanoparticles and their entrapment at the grinding interface. This action results in the formation of a durable tribofilm that effectively improves the slipping of grains between the wheel and the workpiece offering advanced "on-site" lubrication under extreme pressure. For soybean oil based fluids, as shown in Figure 10, the improvement with the nanoparticle-based lubricant is relatively less as compared to the other two groups. The reduction in grinding forces with nanoparticle-based lubricant additive (both low and high concentration) is less, and there is virtually no improvement of friction between the wear flats and the workpiece compared to that of pure soybean oil (without nanoparticle-based lubricant). This indicates that the improvement of lubrication with nanoparticle-based lubricant additive could also depend on the base fluid chemistry, which will guide their interaction (teaming) with the molecules of emulsifier and canola oil present along with the MoS_2 nanoparticles. Thus the selection of appropriate base fluid is also critical in the application of nanoparticle-based lubricants in MQL grinding and requires further course of research in this field.

Grinding Ratio (G-ratio)

Wheel life in grinding process is expressed in terms of grinding ratio or G-ratio and is defined as the volume of material removed per unit volume of grinding wheel wear. Wheels with a high G-ratio last longer than those with lower G-ratios. The G-ratio results for all the grinding experiments are shown in Figure 11.

It is important to note that G-ratio is higher for high concentration of nanoparticle-based lubricant additive conditions for all the base oils, including soybean oil. We believe that this can be explained by the reduction in grinding forces with nanoparticle-based lubricant additives, thereby, ensuring the retention of grit sharpness due to less wear and lower plastic deformation at reduced temperature. It is important to bring out that the effect on tangential grinding forces for pure versus additive contained soybean oil are miniscule, however G-ratios are distinctively higher.

CONCLUSIONS

It is shown that either in the coating form using unique bio-mimetic over-layer of solid lubricants or using uniquely engineered colloidal chemistries of solid lubricants one can enhance efficiency of manufacturing and machining. In the case of as-produced cBN-TiN composite coating, biomimetic surface structures similar to that of a lotus leaf; those surface structures can be applied as nano-micro-reservoirs to effectively entrap application-specific solid lubricant particles. Tribotests showed that sliding of cBN-TiN against a 440C stainless steel ball resulted in a very high coefficient of friction (μ = 0.65), but with tumbled MoS_2 particles sliding friction was significantly reduced to an intermediate level (μ = 0.28), and it was comparable to that of a PVD MoS_2 coating on a tool insert substrate. The biomimetic cBN-TiN coating surface is effective in entrapping nano-micro-particles, and application-specific solid lubricant particles can be applied for various tribological applications. In liquid colloidal lubricant applications, it is shown for the first time that nanoparticles of MoS_2 could provide key value addition in MQL grinding, when using various off the shelf base fluids such as paraffin oil, soybean oil and CANMIST oil. Also, it is reported that the nanoparticles of MoS_2 offer unique advantages in MQL when they present the possibility of navigating in the grinding zone and delivering reduction of grinding forces (27% for CANMIST oil group, 21% for paraffin oil based group and 9% for soybean oil group), and most distinctively increase life of expensive grinding wheels by increasing G-ratio (46% for CANMIST oil group, 35% in paraffin oil group and 15% in soybean oil group). Superior grinding performance with minimum application of nanoparticle-based lubricants (5 ml/min compared to 5400 ml/min application in flood cooling) shows its cost-effectiveness. Last but not of the least importance, MoS_2 is relatively environmentally friendly along with Canola oil and lecithin chemistry. Thus these novel solutions present significant opportunities for sustainable engineering in machining and manufacturing using superabrasive tools. ■

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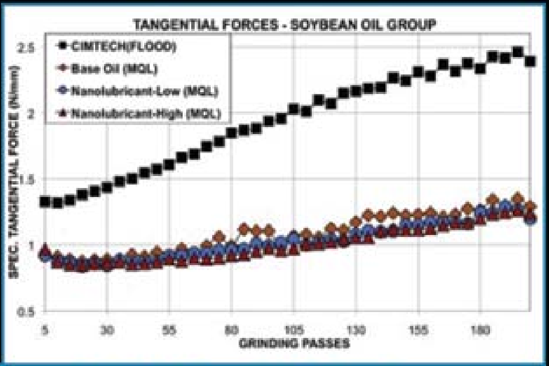

FIGURE 10: *Tangential Grinding Forces vs. Grinding Passes - Soybean Oil Group*

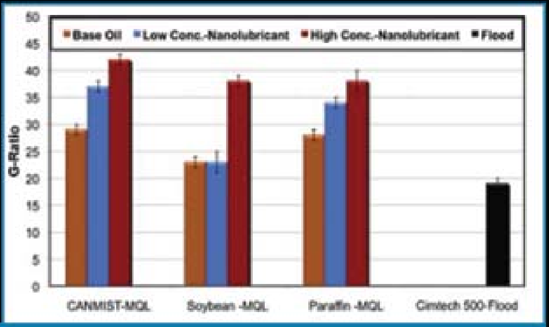

FIGURE 11: *Grinding Ratio Results*

Acknowledgements - Authors acknowledge financial support of National Science Foundation (NSF) for part of this work. Also, we acknowledge technical discussions/contributions of Dr. Wu.

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Worthington, OH, June 9, 2010 –
Diamond Innovations, a leading manufacturer of diamond, cubic boron nitride and polycrystalline products, has recently received awards for safe working practices at all of their locations. The Worthington, Ohio factory received the highest level of recognition for a facility as an OSHA **Voluntary Protection Program (VPP) Star site**. The VPP Star program consists of companies who have established independent safety controls and maintained injury and illness rates below national averages. The National Safety Council (NSC) awarded the Deerfield Beach, FL facility with the **2010 Safety Leadership Award** for having zero OSHA recordables or Lost Time Accidents since 2004. They also awarded the Dublin, Ireland operation with the **2010 Perfect Record Award** for maintaining a perfect record in OSHA recordables and Lost Time Accidents in 2009. Tanya Fratto, CEO of Diamond Innovations, commented, "This is a great recognition for Diamond Innovations and is the result of our dedicated employees who put safety first." For additional information contact Libby Culley libby.culley@diamondinnovations.com

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In Memoriam ... DAVID PRYOR

David W. Pryor, President and CEO of Radiac Abrasives, Inc. passed away on June 14, 2010. A mechanical engineer by trade, Mr. Pryor began his career in the grinding wheel industry in 1975 spending 15 years with Norton Company and holding key Director level positions in both Manufacturing and Marketing. In 1990 Mr. Pryor joined Abrasive Industries Inc. (the former Bay State Abrasives) as Director of Business Development. Mr. Pryor came to Radiac in 1991 as the company's General Manager. He was named President in 1996 and President and CEO in the year 2000. With Tyrolit's acquisition of Radiac in 2009, Mr. Pryor continued in this role expanded to include Tyrolit's Precision Abrasive business in North America. Radiac Abrasives Inc. - A Tyrolit Company has manufacturing facilities in Salem, Oswego, IL, Marysville, WA and Tijuana, Mexico. The company employs nearly 500 people in North America. In a career than spanned 35 years, Mr. Pryor became a leading figure in the grinding wheel industry and its trade organization UAMA, the Unified Abrasives Manufacturers' Association and served on its board of directors. Mr. Pryor was an avid golfer, fisherman, and hunter. Mr. Pryor leaves behind his wife Susan (Samorajczyk) Pryor of Salem, a son Jonathan Pryor of Salem, two daughters: Johanna Myers and husband Brandt of Naples, Florida and Katherine Hahn and husband Brian of Chicago and a sister Caroline Pryor and husband David MacDonald of Mount Desert, Maine, as well as nieces and nephews. All his family, friends and colleagues in this industry will sadly miss David.

In Memoriam ... RICHARD MARK ANDREWS

Richard Mark Andrews passed away at age 49 on Tuesday the 20th of April 2010 at his home in Long Valley, New Jersey. He was born in Croydon, England on the 24th of May, 1960 to Peggy and Colin Andrews and is survived by them as well as his wife of 22 years, Sandy, children Fiona (19) and Geoffrey (15), brother Simon and his family, hundreds of friends, and dozens of pet fish. After finishing boarding school in England, he graduated from Southampton University (England) and went on to earn a PhD in Course 3 Material Science at the Massachusetts Institute of Technology in 1991. He was employed by Brunswick Defense in Lincoln, Nebraska, and Temav in Venice, Italy. In 1999, he moved near to Worcester, Massachusetts when he began working at Saint-Gobain Corporation as a Senior Research Engineer. In 2000, he moved to Long Valley to work as the VP of Engineering at GIDCO, and in 2009 left the company to work for himself as a consulting engineer. During his career, he had over a dozen patents for his work in superabrasives, and he was a member of ASM International Society and New Jersey MIT Alumnae Association. He enjoyed family vacations to Cape Cod every year and to Europe whenever possible. He had many passions including building model airplanes, Monty Python, participating in local politics, activism, a love for cars that led him to collect Jaguars and race Porsches and a "thrill-seeking gene" that led him to earn a private pilot's license so he could fly whenever he liked. He also enjoyed scuba diving, skiing and tennis. Richard will be remembered for his fearlessness, zaniness, helpfulness, vivacity, love for life and humanity, brilliance, awesome hugs, and funny faces. He will be greatly missed by his family and friends.

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2010 EDITORIAL CALENDAR

Planned issues, topics and closing dates:

Issue:	Editorial Feature*:	Closing
Spring 2010	Superabrasives Resource Directory	Mar. 15, 2010
Summer 2010	Nanotechnology & Materials	May 15, 2010
Fall 2010	IMTS Preview & Machine Tools	Aug. 15, 2010
Winter 2010/2011	INTERTECH 2011 Program & Registration Packet	Nov. 15, 2010
Spring 2011	INTERTECH 2011 Presentation Preview	Feb. 15, 2010

*Editorial topics subject to change

SHIPPING INSTRUCTIONS

Fax, mail or email all printing materials to:

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HUIFENG DIAMOND

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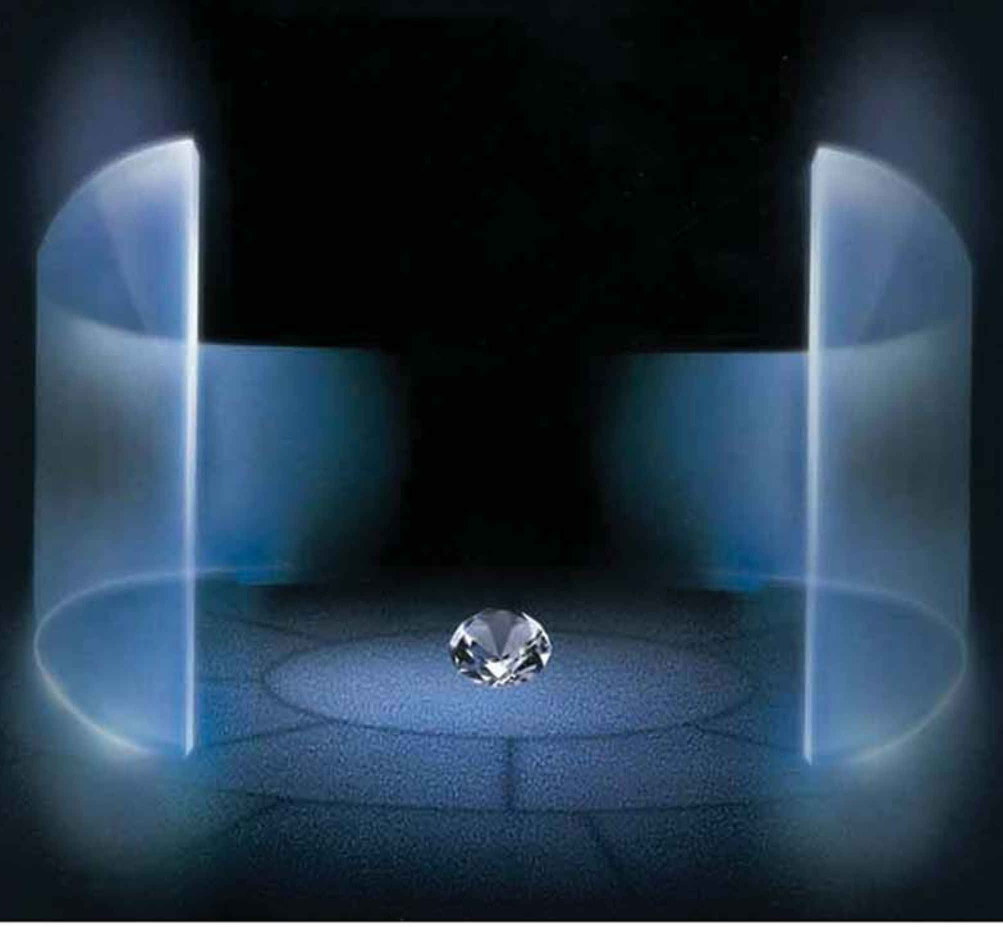

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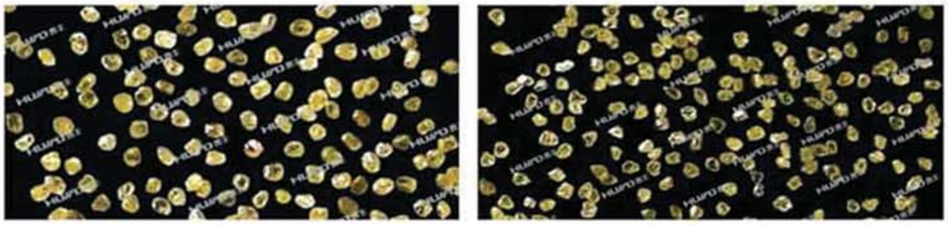
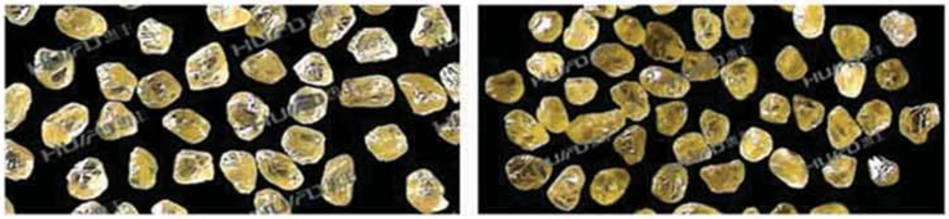


Diamond Mesh Powder (JR1)



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Industrial Diamond Association of America, Inc.

MEMBERSHIP APPLICATION

Company ______________________________ Address ______________________________
City ____________________ State ______ Zip Code/Postal Code ____________ Country ______________
Shipping Address (Can not ship to PO Box) ______________________________
City ____________________ State ______ Zip Code/Postal Code ____________ Country ______________
Phone ______________________________ Fax ______________________________
E-mail ______________________________ Web Site ______________________________
Official Representative ______________________________
Others (Participating in IDA Activities) ______________________________
Principle Business Activity ______________________________
Which applies to your company: ______ Corporation ______ Partnership ______ Sole Proprietorship
Provide names of principle officers or partners: ______________________________
When was your company established? ____________
How long has your company been engaged in superabrasive/ultra-hard material industry? ________

List at least two business references, preferably one is an IDA member (name, company and address of each):
1. ______________________________
2. ______________________________

CHECK APPROPRIATE MEMBERSHIP

______ **Regular Membership**

Any company and/or individual classified as a superabrasive/ultra-hard material supplier, tool maker, machine tool builder, end user or related business with offices in the USA, Canada or Mexico is eligible in this category. Only one individual shall be designated by each member company as the IDA Delegate with voting and other privileges described in the By-Laws.

(DUES CATEGORY)

The dues category for Regular Members is determined by annual sales volume expressed in US $ as indicated below.
Check to appropriate category:

_____	Category 1	$2,575 per year	Over $20,000,000 Annual Sales
_____	Category 2	$1,936 per year	$10,000,000 - $19,999,999 Annual Sales
_____	Category 3	$1,709 per year	$6,000,000 - $9,999,999 Annual Sales
_____	Category 4	$1,328 per year	Under $2,000,000 - $5,999,999 Annual Sales
_____	Category 5	$975 per year	Under $1,999,999 Annual Sales

Name of Delegate Voting Member: ______________________________
Title: ____________________ E-Mail: ______________________

______ **International Membership**

Any company and/or individual classified as a superabrasive/ultra-hard material supplier, tool maker, machine tool builder, end user or related business which does not have offices or other facilities in the USA, Canada or Mexico is eligible in this category. An International Member shall have all the privileges of regular membership, except that the delegate cannot vote at any membership meetings, participate in statistical reporting for the North American market, hold proxies or serve in any office in IDA. Annual fee for International Member is **$2,575 per year**.

Name of Delegate Voting Member: ______________________________
Title: ____________________ E-Mail: ______________________

______ **Associate Membership**

Available for companies having a principal office in the USA, Canada or Mexico, which are providing products or services to the superabrasive/ultra-hard material industry, but are not engaged in selling, using or dealing in industrial diamonds, cubic boron nitride, compacted diamond/cbn, diamond film or products containing diamonds/cbn. An Associate Member shall have all the privileges of regular membership, except that the delegate cannot vote at any membership meetings, participate in statistical reporting for the North American market, hold proxies or serve in any office in IDA. Annual fee for Associate Member is **$500 per year**.

Name of Delegate Voting Member: ______________________________
Title: ____________________ E-Mail: ______________________

______ **Affiliate Membership**

Each company that enrolls as a Regular or International IDA Member is entitled to have a second person at that company designated an Affiliate Member. The first Affiliate member will receive IDA material at no further cost. Additional persons at Member companies can be added as Affiliate Members to receive IDA materials. Annual fee for Affiliate Member is **$75 per year**.

Name of 1st Affiliate Member (no charge): ______________________________
Name of 2nd Affiliate Member ($95): ______________________________
Name of 3rd Affiliate Member ($95): ______________________________
If more than 3 Affiliate Members, please attach separate sheet.

______ **Education/Research**

Any individual having an affiliation with a non-profit educational institution or Research & Development organization is eligible for membership in this category. An Education/Research Member shall have all the privileges of regular membership, except that the delegate cannot vote at any membership meetings, participate in statistical reporting for the North American market, hold proxies or serve in any office in IDA. Annual fee for Education Member is **$125 per year**.

______ **Senior Membership**

Available for any individual who has retired or is no longer active in the diamond or cbn business, but wishes to receive information mailings and attend IDA meetings as a member. Annual fee for Senior Member is **$50 per year**.

WHAT IS THE IDA?

The Industrial Diamond Association of America, Inc. **is a non-profit trade association and was incorporated on March 29, 1946 in the State of New York. It is the oldest and most prestigious association in the superabrasive/ultrahard materials industry. Activity and focus has evolved from natural diamond to superabrasives and most recently, to all ultrahard materials including CVD Diamond. Members include material suppliers, tool manufacturers, component producers, machine tool builders, end users, academia/research affiliates and other companies related to the research, manufacture, application, use and sales of superabrasives.**

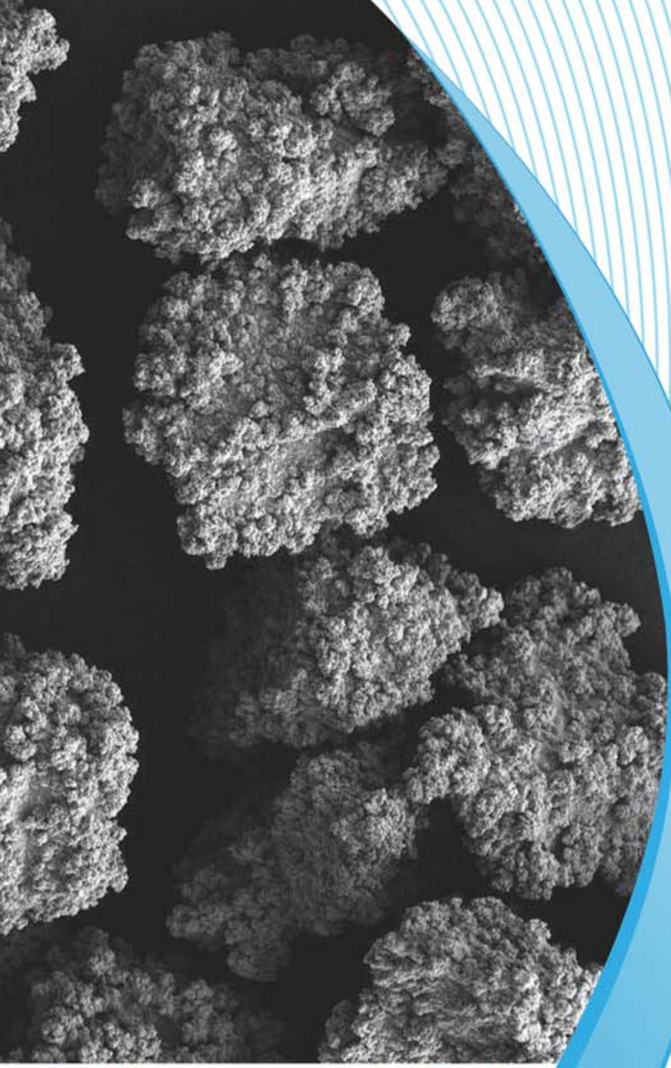
WHAT DOES THE IDA DO?

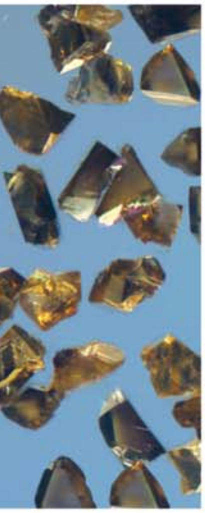
- **Oversees Statistics Reporting Program**
- **Establishes Industry Standards**
- **Interacts With Global Associations And Organizations**
- **Creates And Distributes Market Studies & Data**
- **Organizes And Presents Technical Seminars & Conferences**
- **Serves As A Government Liaison For Industry Guidelines And Regulations**
- **Participates As Member Of World Diamond Council**
- **Provides Safety / Regulatory Reports And Advisement**
- **Resource For General Information And Consultation**

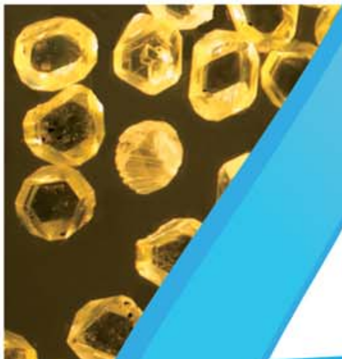
OTHER MEMBER SERVICES

- **PUBLISHES QUARTERLY MAGAZINE**
- **HOLDS ANNUAL CONVENTIONS**
- **HOSTS IDA WEBSITE WITH MEMBER FOCUS AND DIRECTION**
- **PROVIDES SPECIFIC ASSISTANCE ON INDIVIDUAL MEMBER ISSUES**
- **CREATES AND DISTRIBUTES PUBLICATIONS ON PRODUCTS AND APPLICATIONS**
- **ACTS AS A COLLECTIVE VOICE FOR INDUSTRY CONCERNS**

FAX COMPLETED MEMBERSHIP FORM TO 614-797-2264







Experience Reliability & Exceptional Customer Service

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WWSA
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Phone: (888) 410-1631 Fax: (888) 410-1630 Web: www.worldwidesa.com

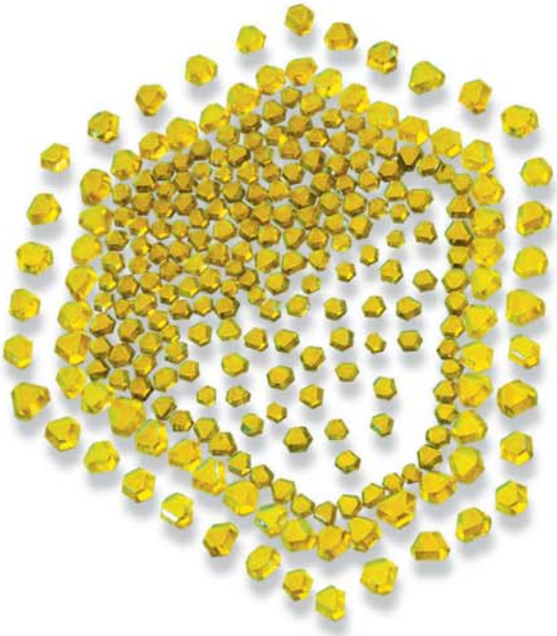
elementsix™

Diamond Abrasives Corporation is making a change.

Diamond Abrasives Corporation, DAC, is changing its name to Element Six.

DAC is one of the leading industrial diamond companies in the US with 40 years of history behind it. Now that is added to Element Six, which has more than 50 years of leadership in the industrial diamond business. The combined experience will now be of benefit to US customers in all industrial diamond markets.

The name change recognizes the fact that DAC is now an integral part of Element Six, an international group operating in more than 70 countries with both technical and market leadership that can deliver real benefits to our US customers. Such benefits include increased links to the company's global manufacturing capabilities, application technical and development expertise across many industries.



As Element Six we are the world's leading supplier of diamond supermaterials. We are the frontrunner in the development of synthetic diamond and novel related engineering materials spanning for example optical, mechanical, thermal and electronic thermal properties for application in such diverse industries as aerospace, automotive, chemical and construction, defence, energy, medical, oil & gas, telecommunications and technologies.

With a turnover of US$ 500m in 2008 and almost 3,000 employees, Element Six has global production and processing plants supported by sales and distribution networks.
You can now buy our products online. Visit www.e6.com

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Element Six – leading the way in industrial diamond